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Research article

The Effect of Short-Term Sport-Specific Strength and Conditioning Training on Physical Fitness of Well-Trained Mixed Martial Arts Athletes

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Abstract

The purpose of the present study was to investigate the effect of a short-term, high-intensity, low-volume Mixed Martial Arts (MMA) specific strength and conditioning training program on performance in national level MMA athletes. Seventeen experienced fighters were divided into two groups: (A) Specific Training Group (STG; n = 10), which followed a specific strength and conditioning program designed according to the demands of MMA competition and (B) Regular Training Group (RTG; n = 7), in which participants followed a regular strength and conditioning program commonly used by MMA athletes. Before and after the four-week training period (3 days per week), body composition, aerobic fitness, strength, power and speed were evaluated. Significant improvements in estimated VO_{2max}, average power during the 2000 m rowing, bench press, back squat and deadlift 1RM, SJ power, CMJ height power, medicine ball throw velocity, 10 m sprint and 2 m take down speed and fat-free mass were found only in the STG (3.7 to 22.2%; $p < 0.05$; Hedge's g = -0.42 – 4.1). No significant changes were found for the RTG (p = 0.225 to 0.811). Significant differences between the groups were found for almost all post-training assessments ($p < 0.05$; Hedge's g = 0.25 – 1.45) as well as for the percentage changes from pre to post training ($p < 0.05$; Hedge's g: 0.25 – 1.45). Significant relationships were found between percentage changes in fat-free mass, endurance capacity, muscle strength/power and speed (r: -0.475 to 0.758; $p < 0.05$). These results suggest that a high-intensity low-volume strength and conditioning training intervention designed according to the demands of MMA competition may result in significant performance improvements for well-trained fighters.

Key words: Combat sports, reality fighting, strength training, power training, body composition.

Introduction

The popularity of combat sports and especially Mixed Martial Arts (MMA), through the Ultimate Fighting Championship (UFC) fights, has been growing fast, with a large number of athletes being involved in MMA training and fights (La Bounty et al., 2011), while the number of spectators and fans has also increased rapidly (Andrew et al. 2009). MMA may be characterized as an intermittent sport with high speed and power activity bursts (James et al., 2016; Lenetsky and Harris, 2012), recurring for three to five 5-minute rounds with 1 minute rest between each round (La Bounty et al., 2011). Thus, MMA is a highly physiologically complex sport, in which a wide spectrum of physical abilities (i.e., strength, power, speed, muscular endurance) and metabolic mechanisms (anaerobic and aerobic) are involved during training and competition (James et al., 2016; Lenetsky and Harris, 2012). MMA athletes are required to use and combine different fight techniques (James et al., 2017a), as well as to have high levels of strength, power, speed, anaerobic power and aerobic fitness, in order to endure the 3-5 rounds of high intensity intermittent efforts (James et al., 2016; Lenetsky and Harris, 2012). These high physical and technical demands stress the necessity for specialized strength and conditioning training programs for these athletes (James et al., 2013; 2016; Lenetsky and Harris, 2012).

There is a limited number of studies and reports that investigated or described the training practices and guidelines for MMA athletes (Amtmann, 2004; Amtmann and Berry, 2003; La Bounty et al., 2011; Lenetsky and Harris, 2012; Tack, 2013). Although the physiological characteristics of successful MMA athletes and the physiological demands of the sport have been recently described and examined (Amtmann et al., 2008; James et al.; 2016; 2017a; 2017b; La Bounty et al., 2011; Lenetsky and Harris; 2012), there is still a need to determine effective training programs. Previous reports suggested that there may be a large variability in strength and conditioning training programs among MMA athletes, while the large volume and high demands of training and competing may lead to fatigue, overreaching or overtraining (James et al., 2013; La Bounty et al., 2011).

High intensity interval training (HIIT) has been proposed as an effective training method to achieve metabolic conditioning and improve aerobic fitness in MMA (James et al., 2013; La Bounty et al., 2011; Tack, 2013). Also, strength, power and complex training as well sport-specific movements using light loads, have also been suggested to improve power and speed of MMA athletes (Tack, 2013). Thus, the purpose of the present study was to compare the effectiveness of a 4-week regular strength and conditioning training program based on circuit training and characterized by high-volume, with a low-volume conditioning training program, including strength and power training, HIIT, and sport specific power exercises, i.e. exercises that are biomechanically similar to movements performed during MMA, such as medicine ball throws simulating a punch. It was hypothesized that the latter program, despite its lower volume and perceived effort, would confer greater improvements in performance parameters that are important for MMA.

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Methods

General design

A two group training study was used to compare the effects of a short-term complementary sport-specific strength and conditioning program with a "regular" strength and conditioning training program commonly used by most MMA fighters. Seventeen experienced fighters were divided according to their pre-training maximum back-squat strength (1RM), into two groups: (A) Specific Training Group (STG, n = 10), which followed a specific strength and conditioning program designed according to the demands of MMA competition and (B) Regular Training Group (RTG; n = 7), in which participants followed a regular strength and conditioning program that is commonly used by MMA athletes. The training intervention lasted 4 weeks, with athletes performing STG or RTG three times per week every 48 hours (Monday, Wednesday, Friday) according to their group assignment, while on the intermediate three days (Tuesday, Thursday, Saturday), all athletes followed the same fighting training focused on technical skills, striking and grappling. During the first visit to the laboratory, athletes were examined by a trained physician for limiting health impediments and they were asked to complete a weekly recall of self-reported physical activity and a medical history questionnaire. Anthropometric assessment and body composition evaluation was also performed. In the second and third visits, they were familiarized with the testing procedures by performing all tests twice. One week after the last familiarization session, the following physical fitness parameters were evaluated with 48 h intervals between tests: (A) Sprint performance, (B) muscle strength, (C) power and (D) aerobic fitness. One week after the end of the intervention these evaluations were repeated. All tests were performed during the morning hours. At least two of the co-authors were present during testing and verbally encouraged the athletes. The best performance in each test was recorded and used in the statistical analysis. During the experimental period, all participants abstained from any other form of physical training, competition, or other strenuous physical activity. In addition, they were instructed to retain their regular eating habits during the training period. To avoid any effects of the last training sessions on performance evaluation, all post-training assessments were performed at least one week from the last training session.

Participants

Responders to a written announcement of the study posted at the local MMA gyms and clubs, reported to the laboratory and were informed about the study protocols and the inclusion criteria. They were asked to complete a weekly recall self-reported questionnaire to determine their level of physical activity, training experience, frequency, duration per session, and total weekly workload. After evaluation of the responders' applications, seventeen professional, national level male MMA athletes who fulfilled the inclusion criteria (described below), underwent the pre-training fitness evaluation and were then assigned according to their squat 1RM (Table 2), into two groups: (A) Specific Training Group (STG; n = 10; age: 28.9 ± 4.2 years, height: 1.81 ± 0.04 m; number of professional bouts: 4.2 ± 2.5; wins: 2.6 ± 1.7; losses: 1.6±1.0) and (B) Regular Training Group (RTG; n = 7; age: 25.7 ± 5.0 years, height: 1.75 ± 0.05 m; number of professional bouts: 3.8 ± 2.0; Wins: 2.4 ± 1.5; losses: 1.4 ±0.9). Initially, 10 athletes were enrolled in the RTG group, however, three of them did not complete the training program due to personal reasons unrelated to the study. The inclusion criteria were: 1) at least three years of systematic MMA training, 2) at least one recent professional fight (<12months), 3) absence of restraining orthopedic and neuromuscular maladies, 4) age range between 18 to 35 years, 5) no use of medications and nutritional supplements, 6) no participation in any competition during the study. Written informed consent was obtained from each participant, after a thorough explanation of the testing protocol, the possible risks involved and the right to terminate participation at will. All procedures were in accordance with the Declaration of Helsinki and approved by the local university ethics committee.

Training

Athletes completed a 4-week training program. Strength and conditioning training was performed three times per week every 48 hours (Monday, Wednesday, Friday), according to the group assignment. On the intermediate three days (Tuesday, Thursday, Saturday), all athletes followed the same fighting training, focused on technical skills, striking and grappling. All participants rested for one day per week (Sunday). The characteristics of the training programs for the STG and RTG are presented in Table 1.

Strength and conditioning sessions, started with a 10-min low intensity warm-up, followed by dynamic stretching exercises of the major muscle groups. STG performed a periodized compound strength and conditioning training program with the first and the third session per week composed mainly of strength and power exercises. Strength exercises included the squat, bench press and deadlift at 80-95% of 1RM. The number of sets, repetitions and the loads used are shown in Table 1. Each squat, bench press and deadlift set was followed by three counter-movement jumps with maximum intensity, medicine ball chest throws (2 kg) and loaded Jump Shrugs with the 45% of deadlift 1RM respectively, with 1 min rest between the 3 reps of each power exercise. Accordingly, 10 min after the end of the strength exercises, athletes of the STG performed a High Intensity Interval Aerobic Training (HIIT) on a rowing ergometer, according to a recently reported protocol (Stevens et al., 2015). The rowing ergometer was preferred over a treadmill, according to evidence presented in a review on combat sport athletes, suggesting more advantageous adaptations in aerobic and anaerobic capacity after rowing training compared with cycling or treadmill exercise, at least in fighters (Kendall and Fukuda, 2011). The STG in the first week completed 5 sets of 60 s all out ergometer sprints (115% of power achieved at the fastest 500 m part of the 2000 m rowing ergometer evaluation of aerobic fitness, as described below) with 4 min passive recovery between each set (Stevens et al., 2015). In the second week, the STG completed 6 sets of 60 s all out sprints on rowing ergometer and on the 3rd & 4th week the sets remained unchanged but the passive recovery was reduced to

3.5 and 3 min for weeks 3 and 4 (Table 1).

The second session in each week was composed of exercises aiming to increase athletes' power and speed. All athletes of STG started their sessions with loaded jump squats in a smith machine (Table 1). Participants, rested for 4 min between sets, during which they performed 8 drop jumps from a 40.7 ± 16.7 cm box (range 15 - 60 cm), according to athletes' optimal drop height, defined as that at which they achieved the highest reactive strength index (RSI; Byrne et al., 2010; Details about the determination of the optimal drop height are presented in the "*Lower body power performance*" section below). A 12 s inter-repetition rest (García-Ramos et al., 2015) was adapted in both loaded jump squat and drop jumps. The last power exercise was, 4 sets of 8 reps of medicine jab punch throws by each arm separately with a 4-kg medicine ball. After 1.5 min of rest between sets, athletes performed 8 plyometric push-ups, with 12 s intra-repetition rest (García-Ramos et al., 2015), and then rested for another 1.5 min. For the plyometric push-ups, athletes started at the lower position, with their elbows at 90º, their chest approximately 5 cm above the floor, with their torso at a straight line and their lower limbs fully extended (only their toes contacted the floor). From this position, they extended their elbows at maximum speed aiming to detach their hands from. Between loaded jump squats and medicine jab punch throws a 5 min resting interval was kept. Then, athletes performed 5 reps of 10 m weighted sled maximum sprints, with 4 min intervals. The external load was adjusted for each participant, aiming to induce a 10% reduction in initial maximum sprint velocity, according to the equation: % body mass = [(-0.8674 · x % velocity) + 87.99], where the required training velocity expressed as a percentage of maximum velocity (Alcaraz et al., 2009). Thus, the external load of the sled was 9.7±1.2 kg. Five 10 m unloaded maximum sprints followed (after 5 min), with 4 min rest in between (Table 1). Accordingly, 10 min after the end of the 10 m unloaded sprints the STG performed a Sprint Interval training (SIT) session (Bravo et al., 2008). Repeated sprints were included due to the nature of the MMA fights which, according to a previous report, have a work-rest ratio of 1:4s (Del Vecchio et al., 2011; Miarka et al., 2018). Thus, participants carried out three sets of six 40m all out "shuttle" sprints with 20s passive recovery between sprints and 4 minutes between sets. Shuttle sprinting involved changes in direction by 180º every 10m.

Athletes of the RTG followed their regular strength and conditioning training routine, which was very similar to a previous report (Lovell et al., 2012), without any intervention from the researchers (Table 2). Three sessions per week were performed, as in the STG group. Sessions 1 and 3, were composed of a circuit workout, aiming to complete

Table 1. The strength and conditioning training programs for the Specific Training Group.

		Week 1	Week 2	Week 3	Week 4	Rest min Intra-rep	Rest min Sets
Sessions 1 & 3							
Strength & Power Exercises	1. Squat	3 x 8 x 80%	4 x 5 x 85%	5 x 3 x 90%	3 x 2 x 95%		3min
	1. Countermovement jumps	1 x 3	1 x 3	1 x 3	1 x 3	1min	
	2. Bench press	3 x 8 x 80%	4 x 5 x 85%	5 x 3 x 90%	3 x 2 x 95%		3min
	2. Medicine ball chest throws	1 x 3 x 2Kg	1 x 3 x 2Kg	1 x 3 x 2Kg	1 x 3 x 2Kg	1min	
	3. Deadlift	3 x 8 x 80%	4 x 5 x 85%	5 x 3 x 90%	3 x 2 x 95%		3min
	3. Loaded Jump shrugs	1 x 3 x 45%	1 x 3 x 45%	1 x 3 x 45%	1 x 3 x 45%	1min	
HIIT	Rowing ergometer	5 x 60 s	6 x 60 s	6 x 60 s	6 x 60 s		3-4min
Resistance Training Volume per session (sets x repetitions x load in Kg)		7821±1155	7199±980	6088±741	2752±309		
Plyometric training for lower body Volume per session (reps x body mass)		827±65	1103±87	1378±109	827±65		
Endurance Training Volume per session (min)		5	6	6	6		
Total Time Per Session (min)		70	85	82	65		
Training Density (%)		32	27	24	28		
RPE		12-14	10-12	10-12	10-12		
Session 2							
Power Exercises	1. Loaded jump squat	4 x 8 x 30%				12 s	4min
	2. Drop jumps	1 x 8 x from the optimal RSI Height				30 s	
	3. Medicine jab punch throws	4 x 8 x 4Kg in each hand				12 s	3min
	4. Plyometric push ups	4 x 8 x (0.72xBody mass)				12 s	
Speed drills	Weighted sled sprints	1 x 5 x 10m (weight inducing a 10% reduction in maximum performance)					4min
	Maximum sprints	1 x 5 x 10m 100%					4min
SIT	Repeated Sprints	3 x 6 x 40m				20 s	4min
Resistance Training Volume (sets x repetitions x load in Kg)		785±559					
Plyometric training for lower body Volume (reps x body mass)		2940±232					
Plyometric training for upper body Volume (reps x 0.72 body mass)		2117±167					
Loaded Sprint Training Volume (m)		50					
Unloaded Sprint Training Volume m)		50					
SIT Volume (m)		720					
Total Time Per Session (min)		70					
Training Density (%)		23					
RPE		12-14					

HIIT: high intensity interval training. SIT: sprint interval training. RSI: Reactive strength index; RPE: Borg's 20 scale Rating of Perceived Exertion.

Table 2. The strength and conditioning training programs for the Regular Training Group.

Sessions 1-3		Week 1 – 4		
		Reps per exercise	Intensity	Rest Between Exercises/Sets
Circuit Workout for Time (Time to complete the reps per exercise)	SET 1. Squat	50	Kettlebells 32 kg (2 x 16 kg)	"For Time" complete the exercises as quickly as possible
	SET 1.Military Press	50		
	SET 1.Swings	100		
	SET 2.Squat	25		
	SET 2.Military Press	25		
	SET 2.Swings	50		
	SET 3.Squat	12		
	SET 3.Military Press	12		
	SET 3.Swings	25		
Endurance	Skipping rope	20 min at 70-80% of Maximum Heart Rate		
Resistance Training Volume per session (sets x repetitions x load in Kg)			11168±827	
Plyometric Training Volume per session (reps x body mass)			0	
Percentage of average Heart Rate During the Circuit Workout			86.4±8.3%	
Endurance Training Volume per session (min)			20	
Total Time Per Session (min)			70	
Training Density (%)			75	
RPE			17-18	

Sessions 2 Circuit Workout	Week 1 – 4				
	Reps per exercise	Intensity	Circuits Sets	Work/rest ratio	Rest Between Exercises/Sets
Swings	33 – 36	Kettlebells (kb) According to fighters' body mass (BM): Body mass < 90Kg = 20 Kg kb Body mass > 90Kg = 24Kg kb	5	1:1	60 s/60 s
Clean and Press	12 – 17				
Sumo Dead Lifts High Pulls	26 – 40				
Endurance: Skipping rope	20min at 70-80% of Maximum Heart Rate				
Resistance Training Volume per session (sets x repetitions x load in Kg)			10368±406		
Plyometric Training Volume per session (reps x body mass)			0		
Percentage of average Heart Rate During the Circuit Workout			85.4±10.9%		
Endurance Training Volume per session (min)			20		
Total Time Per Session (min)			65		
Training Density (%)			65		
RPE			17-18		

RPE: Borg's 20 scale Rating of Perceived Exertion.

a certain number of repetitions in each of the three sets of the following exercises: [1] Squat, [2] Military press and [3] kettlebell swings. The repetitions of each set were required to be completed in the shortest time possible, a training system known as "For Time". The number of repetitions in each set is represented in Table 2. All exercises were completed against kettlebells weighing 32 kg (2 x 16 kg by each arm). There was no rest between exercises, only few seconds if and when was individually needed. After the circuit workout, all athletes completed 20 min of rope skipping at an intensity equal to their 70-80% of the predicted maximum heart rate. The second session was also a circuit workout, in which fighters were instructed to perform as many repetitions as they could in 1 min. The selected exercises were: kettlebell swings, clean and press, sumo deadlifts high pull, and all participants completed 5 circuit rounds against a kettlebell weight according to the athletes' body mass (i.e., body mass <90 kg = 20 kg, body mass >90 kg = 24 kg). The rest between exercises was 1 minute and there was no extra resting time between rounds. At the end of the session, fighters in the RTG also performed 20 min of rope skipping, as described above.

Training volumes, total time per sessions, training density and the rating of perceived exertion (RPE), were obtained and calculated according to previous reports (Bompa and Haff, 2009) and were compared between the two groups (Tables 1 and 2). The fighting training programs were designed and supervised by an experienced MMA coach. The two hour fighting sessions consisted of regular and commonly used in MMA exercises for improvement in technical skills, striking (standing fight), and grappling (ground fight), as previously described (James et al., 2014).

Procedures

The test battery used in the present study aimed to assess main physical abilities that are important for MMA performance (James et al., 2014; 2016; Kendall and Fukuda, 2011; Tack, 2013). Strength was assessed using standard free-weight tests for upper and lower body (squat, bench press, deadlift), leg power was assessed by squat and countermovement jumps, arm power by one-arm medicine ball throws, and speed was evaluated by a 10 m sprint and the sport-specific 2 m take down sprint test. Aerobic fitness was assessed by a rowing test, as Kendall and Fukuda (2011) suggested that rowing training may be more appropriate to develop simultaneously aerobic and anaerobic fitness in combat athletes.

Evaluation of body composition and anthropometric characteristics: Body composition was evaluated via bioelectrical impedance analysis (BIA; 50Hz; Bodystat 1500, Bodystat Ltd, Ballakaap, Ballafletcher Road, Cronkbourne, Douglas, Isle of Man). Measurements for the estimation of body fat (percentage and kg) and free fat mass (FFM) were highly reliable as shown by the high intraclass correlation coefficient (ICC) [body fat = 0.93, (95% CI: Lower = 0.89, Upper = 0.97), FFM =0.98, (95% CI: Lower = 0.95, Upper = 0.99), $p < 0.0001$, n = 10] as evaluated in a recent study (Papadopoulou et al., 2017).

Sprinting performance: Sprinting performance was evaluated by two tests, 10 m sprint and the sport specific 2 m take down sprint test. The 10 m sprint evaluation was measured indoors on a track surface. Two pairs of wireless photocells (Brower Timing System, USA; accuracy 0.01 s), were placed at 0 m and 10 m for recording the time taken to run the 10 m distance. All participants performed 3 trials with maximal effort, separated by 5 min intervals and the best time was used for analysis (ICC = 0.91, 95% CI: Lower = 0.88, Upper = 0.95; n = 15). In order to evaluate the sport-specific sprinting ability for MMA fighters, the 2 m take down sprint test was performed (Figure 1). A take down is a technique that involves off-balancing an opponent and bringing them to the ground, typically with the attacker landing on top. During a typical take down, the attacker's arms are wrapped around the opponent's torso, and one leg is placed behind the opponent's legs, in order to unbalance them. Two pairs of photocells were used (Brower Timing System, USA; accuracy 0.01 s). The first pair was placed 2 m before a 75 kg training dummy at a height of 1.20 m and the second pair was placed 1 m behind the training dummy at a height of 30 cm above ground (Fig. 1). Each fighter was standing 30 cm behind the first pair of photocells and were instructed to perform a take down, as described above, as fast as possible while maintaining the appropriate take down technique. The timer started when the body of the fighter interrupted the first photocell beam, and stopped when the dummy interrupted the second photocell beam when falling on the ground (Figure 1). All participants performed 3 consecutives trials with maximal effort, separated by 5 min intervals and the best attempt was used for further analysis. The ICC of this test was determined in two different days, prior the study in 10 MMA athletes, and was 0.94 (95% CI: Lower = 0.91, Upper = 0.97).

Power performance evaluations: Upper body power performance: For the upper body power performance, a single arm jab punch medicine ball throw (2 kg) was used. Subjects were asked to stand in a guard position (the basic defense position in MMA, which allow the players to defend against a striking opponent, with their hands close to the jaw and the elbows close to their thorax) and throw the medicine ball at maximum speed, aiming at a square (1 m x 1 m) marked on a wall 2 m high and 5 m away. Speed was evaluated by a Radar Gun (SR3600, Sports Radar Ltd, Florida, USA) which was placed individually over each subject's shoulder. Subjects had 3 attempts for both right and left arm and only the best from each hand was used for further analysis. All the attempts had 1 min rest between them, while they were performed with the right and left arm alternatively. ICC was 0.93 (95% CI: Lower = 0.88, Upper = 0.95; n = 10).

Lower body power performance: Counter movement jumps (CMJ) and Squat jumps (SJ) were performed on a Chronojump Boscosystem contact platform (Asociación Chronojump para la Investigación y Difusión de la Tecnología Aplicada a la Actividad Física y el Deporte, Spain).

Three maximal efforts for each type of jump were performed, with the hands placed on the hips, with 1 min rest between attempts. Jumping height and power were calculated from the Chronojump software, version 1.7.0 (Sayers et al., 1999). The best effort, based on jump height, was used in further analysis. The ICC for the SJ and the CMJ were 0.90, (95% CI: Lower = 0.89, Upper = 0.99) and 0.91, (95% CI: Lower = 0.90, Upper = 0.99) respectively, n = 13. In the pre-training evaluations,

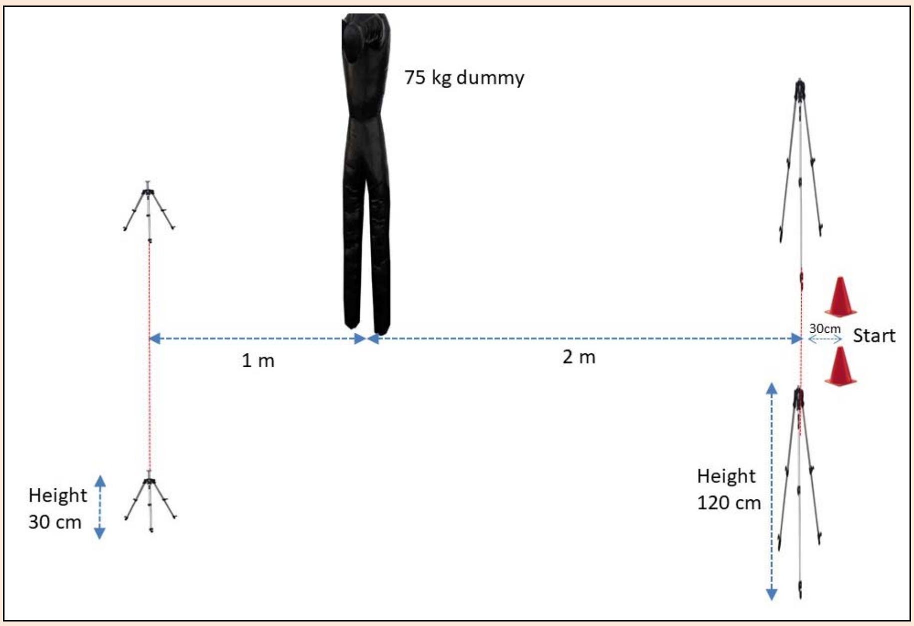

Figure 1. Schematic illustration of the take down test.

jumping performance was also measured in Drop Jumps (DJ) from different boxes height, to identify the individual optimal drop height, at which the highest RSI was achieved (Byrne et al., 2010). This was then used during their training. Participants were asked to step off a wooden box from heights of 15, 30, 45, 60 and 75 cm, without lifting their center of gravity (Byrne et al., 2010) and land on the center of a Chronojump Boscosystem contact platform A2 Din size (Asociación Chronojump para la Investigación y Difusión de la Tecnología Aplicada a la Actividad Física y el Deporte, Spain), with both legs, then they rebounded and immediately jumped as high as possible. Prior to each attempt, athletes were instructed to jump as quickly and as high as possible after landing (Byrne et al., 2010). Subjects performed three DJ from each box height with 1min of rest between jumps. RSI was calculated according to the following formula (Byrne et al., 2010): RSI ($m.s^{-1}$) = maximal DJ height ground contact time^{-1}. ICCs for the DJ parameters were as follows: jump height: ICC=0.95 (95% CI: Lower = 0.91, Upper = 0.97), contact time: ICC=0.96 (95% CI: Lower = 0.94, Upper = 0.98) and RSI: ICC=0.99 (95% CI: Lower = 0.96, Upper = 1.00).

Evaluation of muscular strength: For the assessment of upper and lower body max strength, three basic exercises were used, with the following order: [1] back squat, [2] bench press and [3] deadlifts. These tests were carried out using a standard Olympic bar and weight plates (Eleiko, Halmstad, Sweden), in a squat rack according to the procedures outlined by the National Strength and Conditioning Association (Haff and Triplett, 2016) using a rest interval of 3 min (Senna et al., 2011). The depth of the back squat was maximum for each athlete (full squat) and was recorded in each trial. In order to consider each repetition as complete, the back of the thigh was required to make contact with the back of the shank. The ICCs for 1-RM strength testing were: [1] back squat: 0.95, (95% CI: Lower = 0.91, Upper = 0.97; n = 12), [2] bench press: 0.91, (95% CI: Lower = 0.87, Upper = 0.93; n = 12) and [3] deadlift: 0.90, (95% CI: Lower = 0.85, Upper = 0.94; n = 12).

Aerobic fitness: Aerobic fitness was evaluated by a 2000 m time trial on the Concept II rowing ergometer (Concept2, Nottingham, UK), according to previous reports (Ingham et al., 2002; Stevens et al., 2015). The drag factor was set according to the body mass of each athlete (Ingham et al., 2002), and ranged between 130 and 140. Heart rate and power were continuously monitored. An estimation of VO_{2max} was obtained according to the following equation, for trained athletes (Hagerman, 1994): $VO_{2max} = [(15.7 - (1.5 \cdot T)) \cdot 1000] \cdot BM^{-1}$, where T was the performance time for the 2000 m rowing bout in minutes and BM the athlete's body mass. The ICC for this evaluation was determined prior to the study, and was 0.90 (95% CI: Lower = 0.87, Upper = 0.92; n=10).

Statistical analyses

Two-way analysis of variance for repeated measures on one factor (group x time) and Bonferroni Post-Hoc was used for the comparison of performance indices pre and post training between the two groups. Hedge's g was used as an indicator of effect size. The magnitude of effect size (ES) for pairwise comparisons, was determined by Hedges' g (small: <0.3, medium: 0.3-0.8, large: >0.8). Student's t-test was used for examining percentage changes of performance pre- and post-training between the two groups.

Pearson's product moment correlation coefficient was used to explore correlations between variables. The interpretation of the observed correlations was performed according to Hopkins' ranking: correlations coefficients between 0.3 - 0.5 were considered moderate, between 0.51 - 0.70 large, between 0.71 - 0.90 very large, and > 0.91 almost perfect (Hopkins, 2000). Statistical analyses were performed with SPSS Statistics Ver. 20 (IBM Corporation, USA). Two-tailed significance was accepted at $P \leq 0.05$. All data are presented as means and standard deviation (±SD).

Results

The RTG performed significantly higher weekly volume load (STG: 16428 kg (week 1) to 6289 kg (week 4); RTG: 32048 kg (week 1) to 34552 kg (week 4), Table 1) and endurance training (STG: 5-6 min; RTG: 20 min) and had higher training densities per session (STG: 23% to 32%; RTG: 65% to 75%) and RPE ratings (STG: 10 to 14; RTG: 17 to 18) compared with STG, during the 4 weeks of the study ($p < 0.01$). In contrast, STG had higher total time per session, ranging between 65 min and 85 min (Tables 1 and 2). Also, the STG performed higher plyometric and sprint training volumes per session ($p < 0.01$) compared to RTG, who did not perform any plyometric and sprint training.

The results of the physical fitness parameters assessed before and after training for the two groups are presented in Table 3. No significant differences were found between RTG and STG for any parameter at the initial evaluations ($p > 0.05$). After the 4 weeks of intervention, significant differences were found for the STG, for most of the performance parameters assessed (Table 3 and Figure 2; $p < 0.05$; ; Hedge's g= 0.14 - 4.1), while no significant differences were found for the RTG (p: 0.23-0.81; Hedge's g= 0.00 – 0.15). Specifically, the STG increased estimated VO_{2max}, average power during the 2000 m rowing, bench press, back squat and deadlift 1RM by 11.5-20% (Table 3).

Additionally, in this group significant increases were also found for SJ power, CMJ height power (6-7%) and for medicine ball throw velocity for both arms (Table 2). It should be noted that the dominant arm was the right for all participants. In all tests which performance was evaluated according to time (2000 m rowing time, 10 m sprint and take down sprint), significant improvements were also found (Table 3). Significant differences between the groups were found for almost all post-training

Table 3. Physical fitness parameters examined before (pre) and after (post) the 4 weeks of training for the specific training group (STG).

	STG (n=10)				RTG (n=7)				
	Pre	**Post**	**% Change**	**Hedges's g within groups**	**Pre**	**Post**	**% Change**	**Hedges's g within groups**	**Hedges's g between Groups**
Body Mass (Kg)	91.8±7.3	92.1±7.6	0.3±1.8	0.03	90.9±6.5	89.3±8.2	0.4±4.7	0.05	0.10
Fat (%)	17.4±4.8	16.7±5.6	-4.5±2.04	0.11	16.8±6.0	17.2±4.3	2.9±4.1	0.06	0.25
Fat (Kg)	16.1±5.5	15.6±6.2	-4.3±2.3	0.07	15.9±4.9	15.7±4.2	3.6±3.8	0.06	0.27
Fat-free mass (Kg)	75.7±6.2	76.4±6.5	3.9±2.5#	0.13	74.9±6.8	73.6±5.4#	-0.8±1.6#	0.00	0.14
Estimated VO_{2max} (ml·Kg^{-1}·min^{-1})	41.5±11.1*	46.2±10.3*#	13.3±14.5#	0.42	41.9±11.4	42.0±12.1#	-0.1±6.9#	0.01	0.69
2000m Rowing Time (s)	476.2±40.4*	459.4±32.4*#	-3.4±2.9#	0.44	477.7±36.2	477.5±36.9#	-0.1±1.1#	0.01	0.50
2000m Rowing Average Power (W)	222.4±59.42*	240.3±53.2*#	11.5±9.3#	0.30	226.2±43.5	221.2±36.1#	-1.8±3.1#	0.01	0.27
Bench Press 1RM (Kg)	92.1±17.3*	106.3±16*#	16.1±7.8#	0.81	90.3±15.9	92.6±15,58#	2.6±1.7#	0.14	0.82
Back Squat 1RM (Kg)	140.7±22.5*	167.1±25.6*#	19.5±10.4#	1.05	137.14±15.17	139.64±16,29#	2.05±8,45#	0.15	1.17
Dead Lift 1RM (Kg)	146.4±20.6*	174.8±18.7*#	20.1±10.7#	1.38	135.0±26.6	136.9±27.0#	1.0±1.9#	0.05	1.63
Squat Jump Height (cm)	31.0±4.6	31.6±3.9	3.0±1.3	0.14	31.2±2.9	31.5±2.2	1.3±3.1	0.12	0.01
Squat Jump Power (W)	1155±102*	1225±80*#	6.1±5.3#	0.14	1104±83	1101±78#	-0.2±1.6#	0.14	0.06
CMJ Height (cm)	33.14±5.2*	35.1±3.8*#	7.4±4.4#	0.42	31.7±5.9	31.5±6.0#	1.2±1.0#	0.06	0.70
CMJ power (W)	1195±122.5*	1230±6*#	3.59±7#	0.36	1152±122	1161±131#	1.2±0.3#	0.07	0.70
Right arm MBT Velocity (m·s^{-1})	10.5±0.9*	11.6±0.8*#	10.8±4.4#	1.18	10.3±1	10.2±1.1#	-0.7±2.6#	0.07	1.36
Left arm MBT Velocity (m·s^{-1})	9.8±0.6*	10.3±0.9*#	5.7±7.5#	0.65	9.5±1.1	9.4±1.1#	-0.3±2.1#	0.03	0.74
10m Sprint (s)	1.95±0.06*	1.88±0.05*#	-3.7±1.4#	1.21	1.93±0.13	1.92±0.10#	-0.4±1.1#	0.06	0.54
2m Take Down Sprint (s)	0.96±0.1*	0.74±0.01*#	-22.0±4.9#	4.10	0.8±0.1	0.8±0.1#	0.5±1.6#	0.03	1.45

STG: Specific Training Group; RTG: Regular Training Group; CMJ: countermovement jump; MBT: medicine ball throw; *: p<0.05 between pre and post training; #: p<0.05 between the two groups

assessments (Table 3 and Figure 2; $p < 0.05$; Hedge's g = 0.14- 1.63). No significant differences were found for post values and percentage changes for body mass, body fat and squat jump height between the two groups ($p > 0.05$).

The correlations between the percentage changes of selected physical fitness parameters are presented in Table 4. Percentage changes of fat-free mass and of 2000m rowing average power showed moderate to large correlations with percentage changes of estimated VO_{2max}, strength tests, power during SJ and CMJ, as well medicine ball throw velocity (r: 0.498 – 0.771; $p < 0.05$). Percentage change of 2000 m rowing time correlated positively with percentage changes of estimated VO_{2max} and deadlift strength (r: 0.525 – 0.758; $p < 0.01$), but negatively with SJ and CMJ power, and right hand medicine ball throw velocity (r: -0.608 – -0.653; $p < 0.01$). Changes in bench press 1RM performance exhibited high correlations with changes in medicine ball throw velocity (r: 0.523 – 0.662; $p < 0.05$), while back squat 1RM was correlated with changes of deadlift 1RM and squat jump power (r: 0.568 - 0.826; $p < 0.05$; Table 4). Bench press and, deadlift 1RM, as well as SJ power changes had significant moderate to large correlations with changes of CMJ power and medicine ball throw velocity (r: 0.496 – 0.671; $p < 0.05$). Strong correlations were shown between changes in CMJ power and medicine ball throw velocity (r: 0.589 – 0.793; $p < 0.05$). Significant positive correlations were found between 10 m sprint and 2m take down sprint performance changes and the changes in fat-free mass, SJ and CMJ power (r: 0.601 – 0.727; $p < 0.01$). In contrast, negative correlations were found between 10 m sprint and 2m take down sprint performances changes and 2000m rowing time, bench press, back squat and deadlift 1RM (r: -0.495 to -0.772; $p < 0.05$; Table 4). Negative correlations were also found between the initial VO_{2max} (r: -0.500; $p < 0.05$) and the percentage changes of bench press, back squat and deadlift 1RM (r: -0.500, -0.483 and -0.551 respectively; $p < 0.05$) and jumping power (CMJ: -0.512, SJ:-0.523; $p < 0.05$). Finally, negative correlations were also found between estimates of aerobic fitness of the participants and their strength, speed and power performances, at the initial evaluations (from -0.495 to -0.601; $p < 0.05$).

Discussion

The main finding of the present study was that 4 weeks of a low-volume, high intensity sport-specific strength and conditioning training program, improved physical fitness of well-trained MMA athletes. In contrast, a higher volume "regular" training program, based

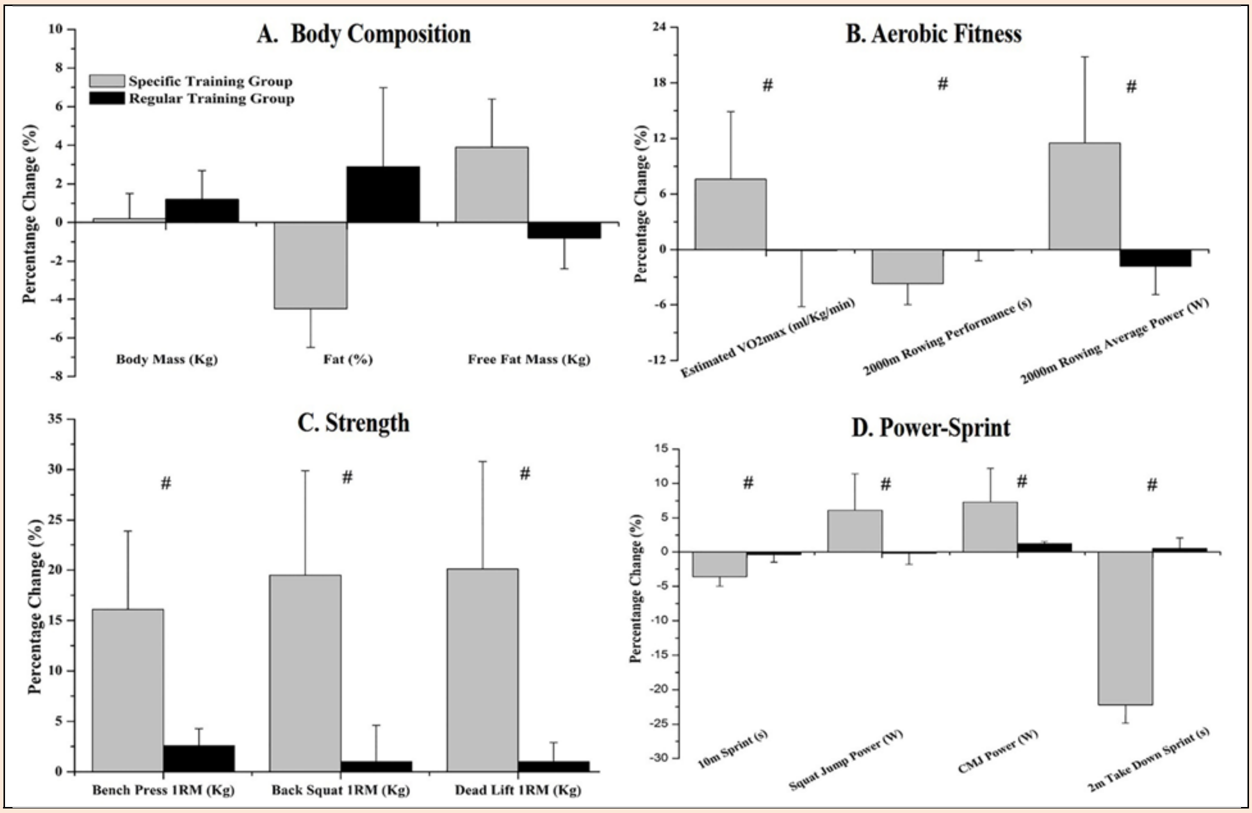

Figure 2. Percentage changes in physical fitness parameters for the specific training and regular training groups. (A) body composition, (B) aerobic fitness, (C) strength and (D) power-sprint parameters. Values are mean ± SD. #: p<0.05 between the two groups.

Table 4. Correlations between percentage changes (Pre to post- intervention values), for all fitness parameters examined (n=17).

Percentage Changes	Estimated VO_{2max}	Back Squat 1RM	Dead Lift 1RM	Squat Jump Power	CMJ Power	Right Hand Medicine Ball Throw Velocity	Left Hand Medicine Ball Throw Velocity	10m Sprint	2m Take Down Sprint
Fat-free mass	0.644#	0.528*	0.483*	0.603#	0.721#	0.498*	0.523*	0.703#	0.685#
2000m Rowing Time	0.785#	0.125	0.525*	-0.608#	-0.608#	-0.653#	-0.400	-0.475*	-0.728#
2000m Rowing Average Power	0.771#	0.638#	0.528*	0.714#	0.714#	0.690#	0.543*	-0.238	-0.422
Bench Press 1RM	0.176	0.441	0.432	0.224	0.314	0.523*	0.662#	-0.679#	-0.772#
Back Squat 1RM	0.204		0.826#	0.568*	0.603#	0.614#	0.598#	-0.495*	-0.668#
Dead Lift 1RM	0.254			0.401	0.549*	0.548*	0.496*	-0.580#	-0.730#
Squat Jump Power	0.180				0.671#	0.670#	0.598#	0.648#	0.727#
CMJ Power	0.140					0.793#	0.589#	0.601#	0.628#

CMJ: countermovement jump; # and *: $p < 0.01$ and $p < 0.05$, respectively ($p > 0.05$).

mainly on circuit training and inducing higher RPE, failed to improve performance in all the tests used.

The STG significantly improved all the examined parameters of speed, strength, power and aerobic performance. Maximal strength plays a key role in MMA performance and especially in grappling actions, while it is also important for the development of high velocity qualities (James et al., 2017b; 2018). The large improvements in upper and lower body strength (16-20%, Table 3), indicate the effectiveness of the STG to improve this important quality for MMA athletes and supports the inclusion of strength training using heavy loads in strength and conditioning MMA programs (James et al., 2017b; 2018). The STG program also improved upper and lower limb power, as shown by the 6-7% increase in CMJ peak power and the 6-11% improvement in peak throw velocity of a medicine ball (Table 3). Furthermore, there was a moderate improvement in 10 m sprint time and a large increase of speed in the sport-specific test of 2m take down sprint (22%, Table 3). These improvements in physical fitness qualities related with MMA performance were due to the fact that the STG targeted these qualities by including heavy strength training, plyometric exercises and specific power exercises, as well as sprint training (Table 1). Also, the 13% improvement in estimated VO_2max in the STG group is possibly due to the high intensity interval rowing training (McInnis and Gibala, 2017). This rowing interval training may have also contributed to the improvements in leg and arm power (Kendall and Fukuda, 2011).

In contrast, the RTG group, which was trained mainly using circuit training, did not improve upper and lower body strength and power, as well as aerobic fitness. The lack of specificity and the excessive fatigue, indicated by the high RPE values (17-18, Table 2), may partially explain the lack of improvement in strength, power and aerobic fitness after 4 weeks of RTG. Thus, according to the above, at least when the target of training is to increase muscle strength and power in trained MMA athletes, circuit type of resistance training, may be ineffective. This type of training may be beneficial for metabolic conditioning (Amtmann and Berry, 2003; La Bounty et al., 2011), but this was not assessed in the present study.

An important finding of the present study, was that strength, speed and power performance of the STG athletes, were increased in an absence of an increase in muscle mass. This finding is important because body mass is taken into account for the selection of opponents in MMA fights. It is a common practice for athletes, to try to lose weight prior to the competition by changing their nutritional and physical activity behavior which, in many cases, leads to significant malnutrition, as certain deficiencies in both macro- and micro-nutrient content ensue (Papadopoulou et al., 2017). Thus, a specific strength and power training program, as that used in the present study, is advised for MMA athletes, as in improves speed, strength and power, with no detectable increase in body mass in the 4 week training period. However, significant muscle hypertrophy is observed after at least 18 sessions of resistance training (Damas et al., 2018), and the longer term effects of the program used in the STG group remain to be examined.

Physical conditioning training programs of MMAs' athletes should aim to improve various aspects of fitness, including improvements of anaerobic and aerobic metabolism, and specific endurance (James et al., 2016; Lenetsky and Harris, 2012; Tack, 2013). Thus, training protocols for MMA athletes should take into account the work to rest ratio that is seen in MMA fights (Amtmann and Berry, 2003; James et al., 2016; 2017a; 2017b; La Bounty et al., 2011; Lenetsky and Harris, 2012; Tack, 2013). In the present study, the combination of the specific HIIT and SIT protocols, with the strength/power training, induced the concurrent development of muscle power and aerobic fitness only in STG, as shown by the reduction of the time needed to complete the 2000m rowing test and the increase of mean power and estimated VO_{2max}. In addition, a previous report suggests that the use of a rowing ergometer is preferred for fighters because it improves endurance, aerobic and anaerobic capacity or the arms and legs (Kendall and Fukuda, 2011). Thus, the combination of resistance training with high intensity, low volume HIIT training, resulted in improvements in muscle power, strength and aerobic fitness, without indications of a negative interaction of strength/power and endurance training (Tsitkanou et al., 2017; Wilson et al., 2012). In contrast, no significant differences were found in the RTG, during which participants performed steady pace rope skipping. The regular use of rope skipping by fighters is an important tool to increase upper-lower body coordination, balance and rhythm (Tack, 2013), but may not be as effective for the improvement of cardiovascular fitness, especially in well-trained MMA athletes. In addition, all the guidelines for strength and conditioning in MMA athletes (Amtmann and Berry, 2003; Tack, 2013), suggest rope skipping as a method for plyometric training and coordination only. According to the results of the present study, HIIT rowing training may be more suitable than long duration rope skipping when the aim is to improve aerobic fitness.

In the present study, significant relationships were found between percentage changes, from initial to post intervention values, in many performance parameters. For example, participants who demonstrated greater improvements in aerobic fitness tended to have smaller increases in strength and power. It is well documented that strength and power cannot be developed to the same extent in the presence of concurrent aerobic training vs. in the absence of aerobic training (Coffey and Hawley, 2017; Hawley, 2008). Another possible explanation for these correlations may be the initial level of aerobic fitness and strength/power. In the present study, participants with lower aerobic performance, had greater improvement in all endurance tests, while at the same time they had higher initial level of strength and power performance, and lower improvements in these parameters after training. According to this observation, the individual response of an MMA athlete to this type of concurrent aerobic and strength training may also depend on their initial level of endurance and strength, respectively. Thus, MMA coaches should take this into account during the preparation of MMA athletes, and should adjust the training regimens according to the baseline strength and aerobic fitness level of each athlete.

An interesting finding of the present study was the positive correlations between changes of FFM and those of sprint performance. In the present study, sprinting performance was evaluated through the time needed from each athlete to complete either a 10 m sprint or the 2 m take down sprint. The correlations showed that a higher FFM lead to slower sprinting performance, which is in accordance with a previous study, reporting that increased musculature was a negative contributor to sprinting performance in trained individuals (Methenitis et al., 2016). In addition, participants of the STG increased their muscle strength, without any significant alterations of their FFM, indicating the present of neural adaptations. The importance of a maximal strength for sprinting performance has been shown in previous studies, as well as in the present study, where relative strength, e.g. $1RM \cdot Body\ Mass^{-1}$ was correlated with sprint times (Chelly and Denis, 2001; Methenitis et al., 2016). The correlations observed in the present study, may also be a useful tool to MMA coaches for monitoring the training procedure, without performing all the tests.

A limitation of the present study, is that RTG training did not include exercises that are close or related with those of the test battery in contrast with the STG. Thus, the test battery used in the present study may have underestimated the effects of RTG training. However, the selection of the evaluations of the present study as well as the training regimens of the STG, were based on previous reports and recommendations (James et al., 2014; 2016; 2017a; 2017b; Kendall and Fukuda, 2011; Tack, 2013).

Conclusion

In conclusion, the present study provides strong evidence that a sport-specific low volume, high-intensity strength and conditioning training program, designed according to the demands of MMA competition, results in large improvements of MMA related fitness parameters, in trained MMA athletes. In contrast, a "regular" training program, including mainly using circuit training, did not improve upper and lower body strength and power, as well as aerobic fitness. The lack of specificity and the excessive fatigue, indicated by the high RPE values, may partially explain the lack of improvement after 4 weeks of RTG. However, the effects of this training on other aspects of MMA fitness were not fully explored, due to the specificity of the test battery.

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Key points

- A 4-week low volume, high-intensity strength and conditioning training program, designed according to the demands of MMA, results in large improvements of MMA related fitness parameters, in well-trained MMA athletes.
- The regular strength and conditioning training program used in the present study did not cause significant improvements in performance in well-trained MMA athletes.
- Physical conditioning training programs of MMAs' athletes should aim to improve various aspects of fitness, including improvements of anaerobic and aerobic metabolism, specific endurance, strength, power and rate of force development.
- Excessive muscle mass may be a negative contributor to sprinting performance in trained MMA athletes. In addition, participants of the STG increased their muscle strength, without any significant alterations of their FFM, indicating the present of neural adaptations.

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